

ELECTRONIC FUNDAMENTALS

THEORY LESSON 40

PRINCIPLES OF COLOR TELEVISION

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Theory Lesson 40

INTRODUCTION

The addition of color to the television image is a great achievement which attests to the ingenuity of engineers and scientists. The sparkle and lifelike quality that color gives to pictures adds to the entertainment value of television. Color in the picture tells a more complete story, thus greatly increasing the usefulness of television for advertising, education, industrial applications, medicine, and other fields.

This lesson will present the basic fundamentals of the color television system. It is assumed that you have a knowledge of the principles of black-and-white television transmission and reception, as given in previous lessons.

40-1. LIGHTS AND COLORS

A study of color television must begin with a study of a few facts about lights and colors.

Light is an electromagnetic radiation capable of stimulating the eye to produce

the psychological sensation of light and color. The position of light in the electromagnetic spectrum is shown in Fig. 40-1. Only a small portion of the electromagnetic spectrum is capable of so stimulating the eye. Different frequencies in this range produce the sensation of red, orange, yellow, green, blue, etc. These different "colors" are more correctly termed *hues*. Differences in deepness of color are described by the amount of *saturation* present. For example, a pale red and a deep red may both have the same hue; the deep red is highly saturated, while the pale red has low saturation. A third characteristic of a colored area is its *brightness*, which is a sensation that depends upon the total amount of light reaching the eye.

These three qualities — hue, saturation and brightness — completely describe the appearance to the eye of any colored area. If the hue, saturation, and brightness are known, the color can be duplicated.

The reproduction of colors, in color television as well as many color reproducing processes, is based on a single experimental fact, which has been known since

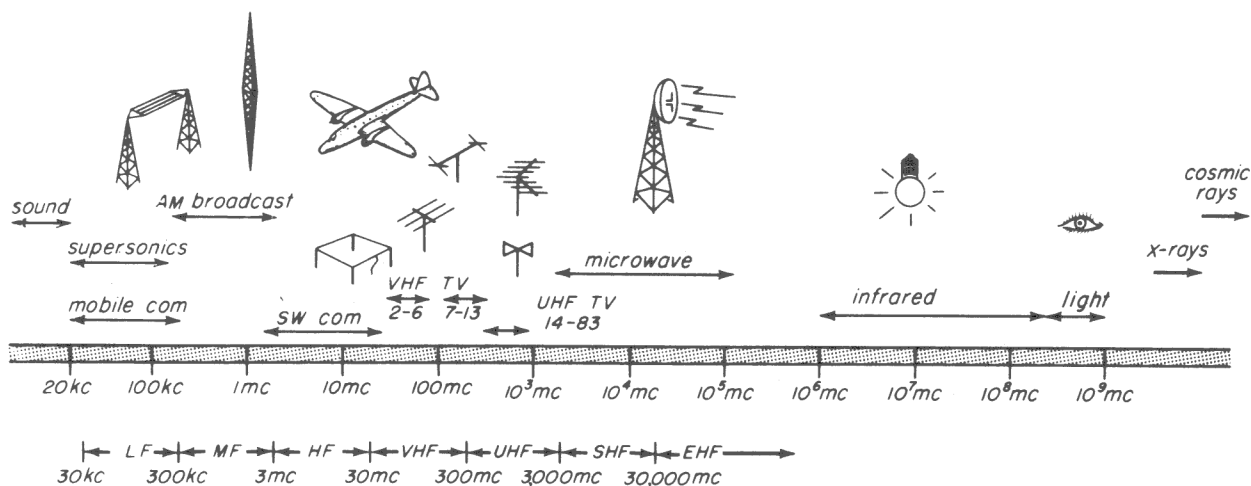


Fig. 40-1

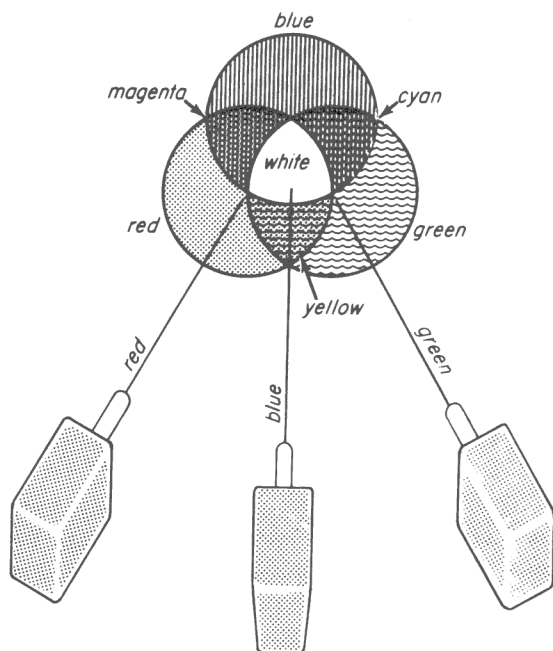


Fig. 40-2

about the 18th century. Almost any color can be reproduced by a mixture of only three colors. That is, as far as the eye is concerned, the visual sensation, or appearance of almost any color can be duplicated by a mixture of certain amounts of only three colors. The three colors used to produce others are called *primary colors*. Almost any set of three primary colors can be used; however, certain sets of colors are capable of reproducing more colors than other sets.

A practical set capable of reproducing the greatest number of other colors consists of *red*, *blue*, and *green*. The major colors that can be produced by mixing together red, blue, and green is shown in Fig. 40-2. Here three projectors are arranged to focus overlapping beams of light on a screen. By means of the red, green, and blue filters in front of the projectors, one projector provides a red beam, another a green beam, and the third a blue beam of light. Where all three beams overlap, *white* light is produced! The overlapping of the red and green beams produces yellow. Where the blue and green beams overlap a green-blue color called *cyan* is produced, and where the red and blue beams overlap a purplish color called *magenta* is formed. By varying the brightness of the light from each of the projectors, intermediate shades

of all kinds may be produced. For example, by varying the amount of green and red light, all the shades of red through orange and yellow to green may be produced.

The hue and saturation of the resulting mixture color depends upon the ratio of red to blue to green; the brightness of the resulting mixture color depends upon the total amount of red, green, and blue. Thus to describe a color, or to reproduce it, we need only know the relative amount of red, blue, and green in the original sample.

When mixing paints or crayons, green, for example, is made by mixing blue and yellow. This is true, and it is not contradictory to what has been said above, that red and green makes yellow. You should get this straight right away: in one case, colored *sources of light* are being mixed together, while in the other case paints or pigments are being mixed. The rules for mixing colored lights are different from the rules for mixing paints or pigments. In color television colored light sources are mixed to produce pictures.

Colored Objects. An object appears colored because when light falls on it, it absorbs some components of the light, and reflects others. A red object appears red because it absorbs all components of the light falling upon it except the red component, which is reflected back to the eye to produce the sensation of red.

If an object absorbs an equal amount of all the components of light, and does not reflect back any color in excess of all others, it will appear neutral or gray. If it absorbs all light, it will appear black.

40-2. AN ELEMENTARY COLOR TV SYSTEM

In accordance with the principles described in the previous section, we can reproduce a color if we know the correct amount of red, green, and blue for that color. But, how can we tell how much red, or green, or blue there is, if any, in a certain color? To answer this question, let us return for a moment to black-and-white tele-

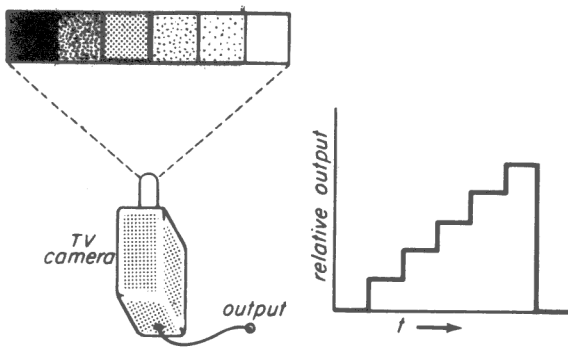


Fig. 40-3

vision principles. Figure 40-3 shows a television camera arranged to scan over a line containing various shades of gray from black to white. The function of the camera in a monochrome (black-and-white) television system is to provide information as to the relative brightness of each element of the scene. The camera does this by giving an output voltage proportional to the brightness of each element of the scene, as shown. Suppose now we were to put a red filter in front of this television camera, as shown in Fig. 40-4. A colored filter allows only light of its own color to pass through. Thus the red filter will only allow red light, and the red component of other colors to pass through to the camera. As shown by the output waveform, output voltage is obtained from the camera only for those parts of the scene containing red. The amount of output voltage is proportional to the amount of red in each element of the scene.

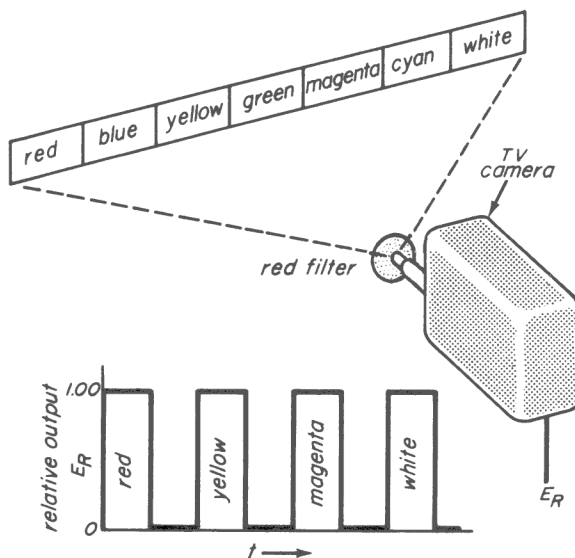


Fig. 40-4

An elementary color television system based on this idea is shown in Fig. 40-5. Three television cameras are used, one with a red filter, one with a green filter, and one with a blue filter. The three cameras are identical, but because the filters allow them to respond only to red, green, and blue light, respectively, we can call them the red, green, and blue cameras, respectively. The output voltage of the red camera, E_R , is proportional to the amount of red in the scene at some particular instant, and similarly for the output of the green camera, E_G , and the blue camera E_B .

Thus, by means of the three cameras and their filters, each element of the scene can be analyzed to find the amount of red, green, and blue contained in that element. The information is obtained in the form of the three camera signal voltages, E_R , E_G , and E_B .

Now let us imagine three kinescopes as arranged in Fig. 40-5. The kinescopes are made with phosphors that glow red, green, and blue, respectively, and the picture area of each kinescope is focused by means of lenses so that the three images fall exactly on top of each other on the screen. At the screen the eye will see the mixture of the three images, just as in the case of the three projectors. Each kinescope is a light source, so that the colors in the image will add in the manner described in connection with Fig. 40-2.

Suppose that in some way the three output signal voltages are transmitted, received, and each applied to the correct kinescope as shown in the figure. The red camera signal voltage applied to the grid of the red kinescope will cause it to trace out a picture in red of the red portions of the original scene. Similarly, the green and blue camera signal voltages will produce images in green and blue, respectively, on the green and blue kinescope. When the three images are combined by the optical system, the eye will see the sum of the separate red, green, and blue images, or a full-color picture.

The arrangement of Fig. 40-5 is a complete color television system, and is the-

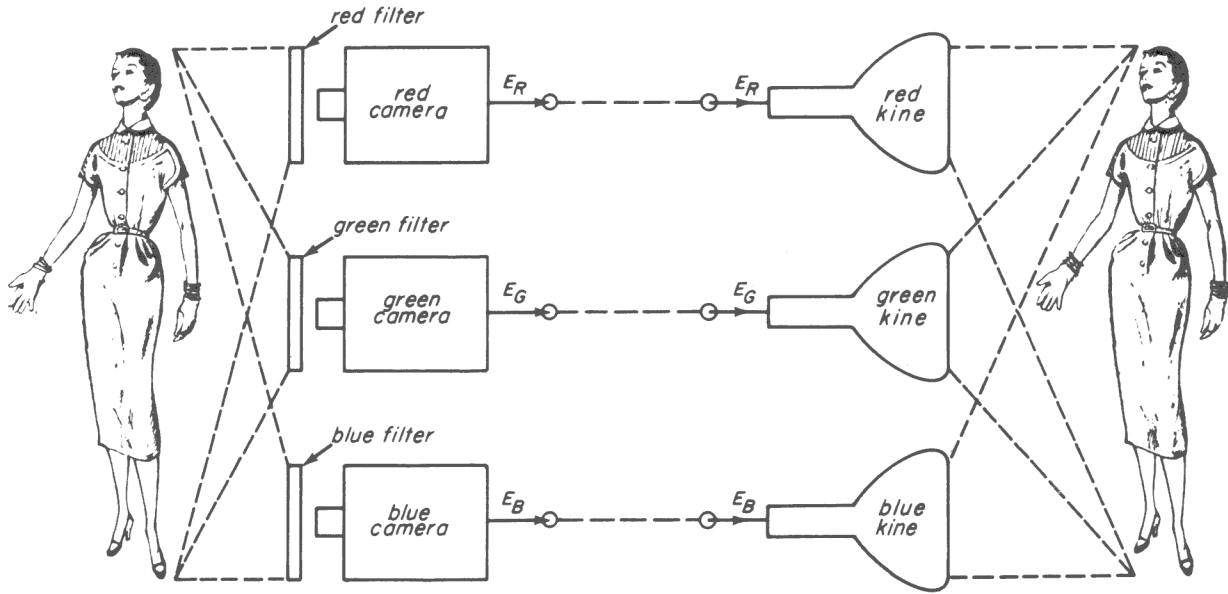


Fig. 40-5

oretically capable of producing excellent color pictures. However, it is not a practical system for television broadcasting, because of the difficulty of broadcasting the three camera output signals from the transmitter to the receiver. In order to understand the further development of the color television system, it is necessary to consider what these transmission difficulties are.

40-3. REQUIREMENTS OF THE COLOR TELEVISION SYSTEM

In previous lessons you have learned that a certain amount of spectrum space is required for broadcasting. The amount of spectrum space required depends upon the amount of information to be transmitted. For example, when a single a-f signal is being transmitted, say 1,000 cycles, two side frequencies are produced. These two frequencies are 1,000 cycles above and below the carrier frequency of the station, as shown in Fig. 40-6a. For speech transmission, sidebands are produced on each side of the carrier, occupying from about 100 cycles to 5,000 cycles on each side of the carrier as in Fig. 40-6b. Music requires still more spectrum space, as shown in Fig. 40-6c. Here a band about 10 kc or more on each side of the carrier is occupied. The information required to reconstruct a television picture is much, much greater than that needed to reproduce voice or music.

The television image is broken up into about 200,000 elements, which means a total of about 8 million picture elements per second. This requires a total bandwidth of 4 megacycles. Sidebands extending 4 mc on each side of the carrier are produced, but to conserve spectrum space only the upper sideband is transmitted, as shown. The diagram in Fig. 40-6d is not drawn to scale — the

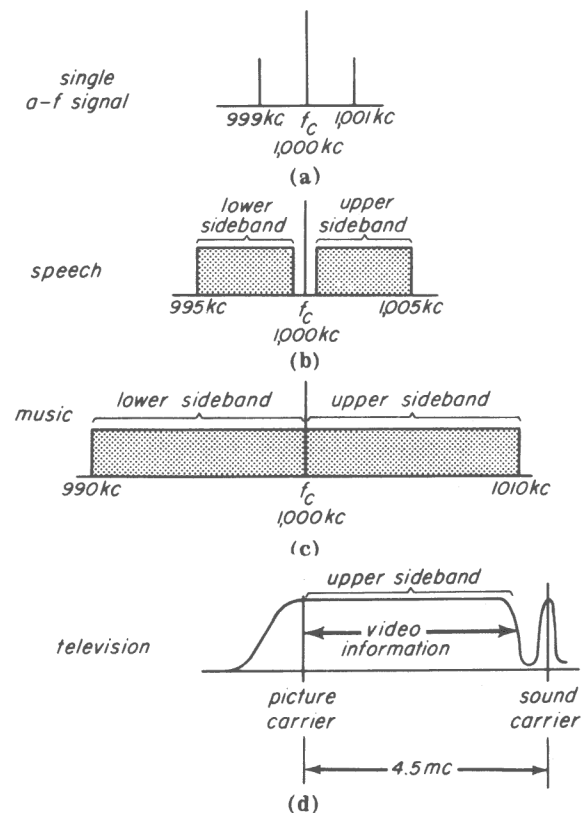


Fig. 40-6

paper is just not big enough. To get some idea of the amount of spectrum space required by a single 6-mc TV channel, consider that the entire AM broadcasting band could be fitted six times into one television channel!

Now let us consider the requirements of color television. Here in addition to sending information about the brightness of each picture element, information must be simultaneously supplied about the hue and saturation of each picture element. Or looking at it in another way, the amount of red, green, and blue in each tiny element must be transmitted at each instant. Any way you look at it, it appears as if three times as much information must be transmitted, requiring three times as much spectrum space. However, due to the great demand for spectrum space, it had been decided long ago by the Federal Communications Commission that no more than 6 mc of spectrum space could be allotted to any one television station, whether black-and-white or color. As we will see, it has fortunately been found that three times as much information and spectrum space are not required.

Careful study of color vision has revealed just how much additional information is required to produce pleasing color pictures. And, ingenious transmitting techniques make it possible to transmit this information without requiring more than the allotted 6 mc of spectrum space.

40-4. COLOR VISION

We do not see small details in color well. In fact, by comparing our ability to see small details in color with our ability to see small details in black-and-white, it could almost be said that we are relatively color-blind. As a result of considerable research the following characteristics of color vision are now known:

1. Very small areas are seen by the eye in shades of black-and-white, regardless of their original color.

2. The color of areas that are intermediate in size is seen by the eye as a

color that is some mixture of orange and cyan, regardless of the original hue and saturation. In other words, only two colors, orange and cyan, are needed to reproduce the color with sufficient accuracy to please the eye, when the colored area is sufficiently small.

3. When the colored area is large, the color is accurately seen by the eye, and all three primary colors (red, green and blue), are needed to reproduce the color with sufficient accuracy to satisfy the eye.

This knowledge that the eye does not see color as well as black-and-white is vital, since it makes possible the transmission of color television within a 6-mc TV channel.

At this point, you may well ask, "What is a small area? How big are an intermediate area and a large area?" The size of these areas can best be defined in terms of video frequencies. From previous lessons you have learned that the scanning of a scene by a television camera produces video frequencies. The actual value of the video frequency depends upon the size of the object image.

The actual value of video frequencies range from about 30 cycles to 4 mc, depending upon the size of the image being scanned. The relatively large black-and-white areas of Fig. 40-7a correspond to a video frequency of 20,000 cycles, whereas the relatively small details of Fig. 40-7b (200 black-and-white elements in the horizontal line) correspond in a video frequency of about 2 mc. The relationship is roughly:

$$\text{video frequency (mc)} = \frac{\text{No. of elements in line}}{100}$$

We can now talk about the size of a picture element in terms of the video frequency that is produced when that element is scanned by a television camera. Large areas are those which produce video frequencies up to about 0.5 mc; intermediate areas are those that produce video frequencies from about 0.5 mc to 1.5 mc; and

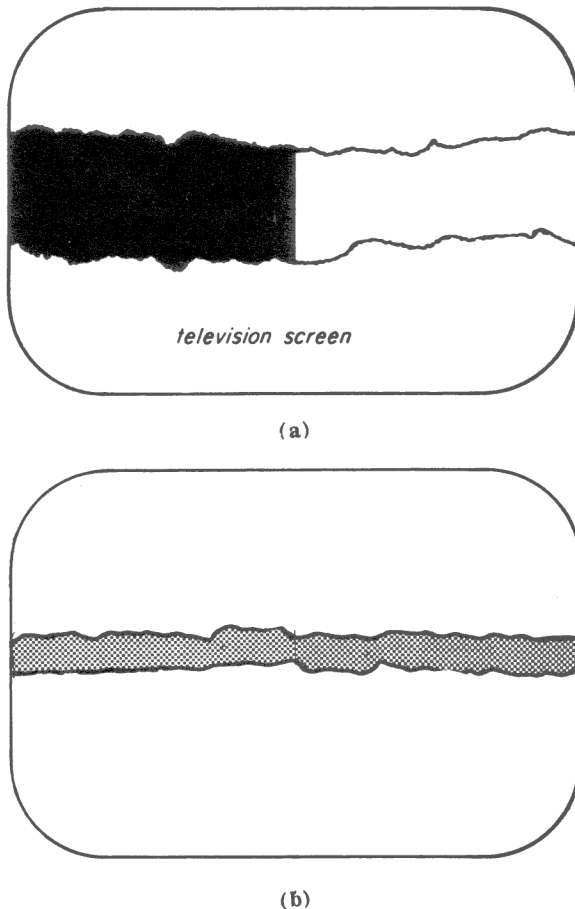


Fig. 40-7

small areas are those that produce video frequencies from about 1.5 mc to 4 mc. The three important facts regarding color vision can then be restated in this way:

1. For small colored areas, corresponding to video frequencies greater than about 1.5 mc, the eye sees no color, and no color information need be transmitted.
2. For intermediate colored areas, corresponding to video frequencies from about 1.5 mc down to 0.5 mc, the eye sees all colors as some mixture of orange and cyan. The only information that need be transmitted in this frequency range is the amount of orange and cyan needed in the mixture to satisfy the eye.
3. For large colored areas, corresponding to video frequencies lower than 0.5 mc, complete three-color information must be transmitted. In this region, the correct amount of red, green, and blue must be known in order for the resulting mixture color to satisfy the eye.

Thus, the necessary saving of spectrum space is partly accomplished by not sending information that the eye cannot use. Color information is sent only when the eye can use it, and is not sent when the eye would not see color even if it is there. In color television, the picture is made somewhat along the lines used in children's paint books. The outline of the image, and its fine details (high-frequency video) such as the contours of the eye, nose, etc., are printed in the book in black-and-white. The child "paints" the picture by merely adding color, with a relatively thick paintbrush, to large areas (low-frequency video). If carefully done, such a picture, when viewed at a distance, gives the sensation of a full color picture. Of course, the color television process, which contains color information up to 1.5 mc, produces a color picture comparable with that of a skilled artist. In fact, present day color television produces pictures that are as good or better than most color reproducing processes.

40-5. THE COLOR SIGNAL

With our knowledge of the color needs of the eye, we can go on to discuss how the color signal is developed. Remember that this color signal must be transmitted in the same space as a black-and-white signal. This is done by arranging the color signal to send only the information the eye can use and no more.

The basic information about how much red, green, and blue there is in each element is still needed, and this is done, as before, by the three camera tube setup like that shown in Fig. 40-8. However, the camera output voltages are not the signals that are transmitted. Since the structure (fine detail) of the picture is going to be accomplished in black-and-white, a monochrome signal is made from the three camera voltages. This black-and-white signal is almost identical to the signal that would be obtained from a monochrome camera viewing the same scene. It is called the *luminance* signal, designated E_Y , and is one of the signals transmitted. In addition to forming the structure of the image,

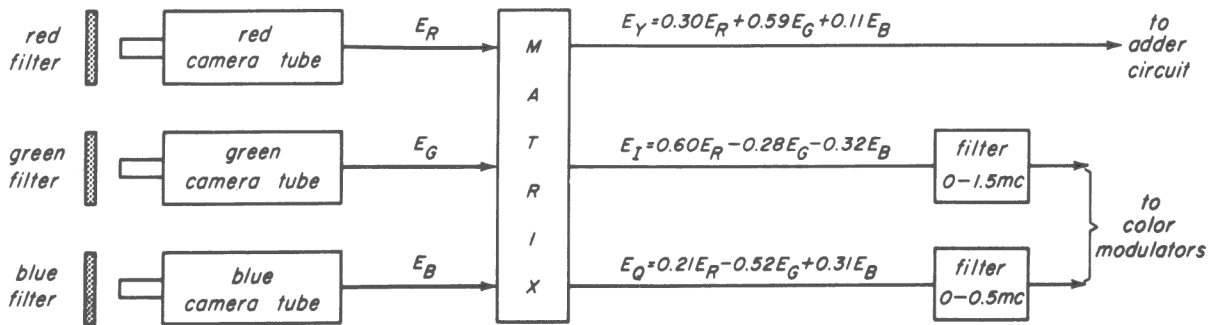


Fig. 40-8

the E_Y signal is used by monochrome receivers to produce black-and-white pictures from a color broadcast. Thus, the color signal is *compatible* — it can be used by both color and monochrome receivers.

The luminance signal is obtained from the camera output voltages by taking a certain portion of each camera signal, in accordance with the equation:

$$E_Y = 0.30 E_R + 0.59 E_G + 0.11 E_B$$

Remember that the E_Y signal is the black-and-white signal, therefore its voltage at any instant should be proportional to the brightness of the particular color being scanned at that instant. To see why the particular values of 0.30, 0.59 and 0.11 have been chosen, refer again to Fig. 40-2. The red, green and blue beams overlap to produce white of a certain brightness. If the blue and green beams are turned off, it is found that the brightness of the red that remains is 30 percent of the brightness of the white. In the same way, it can be determined that the contribution of the green beam to the total brightness is 59 percent, and the contribution of the blue beam is 11 percent. Thus, the E_Y signal, made in accordance with the above formula, will give an output voltage proportional to the brightness sensation of the various colors, or a true black-and-white camera signal.

The operation that is performed on the red, green, and blue camera signals to obtain the E_Y signal is called *matrixing*. This is done in a section of the camera called the matrix as shown in Fig. 40-8. In its simplest form, the matrix can be considered as a resistive combination of voltage dividers, as in Fig. 40-9. For example, the

red matrix could consist of any two resistors whose value is in the ratio of 3 to 7. The voltage across the smaller resistor would then be 30% of the input voltage, as required by the formula. The three voltage dividers are connected together, so that the output voltage is the sum of the individual voltages.

Now two other signals are formulated in the same matrix to carry the color information. Above 0.5 mc, the eye requires information only regarding the orange-cyan content of each element of the scene. A signal called the *I* signal is formed according to the formula:

$$E_I = 0.60 E_R - 0.28 E_G - 0.32 E_B$$

These numbers are chosen to take such proportions of the red, blue and green camera voltages that the *I*-signal carries information about the orange and cyan content of the scene.

A second signal called the *Q* signal is also formed, in accordance with the formula:

$$E_Q = 0.21 E_R - 0.52 E_G + 0.31 E_B$$

These numbers are so chosen that the *Q*-

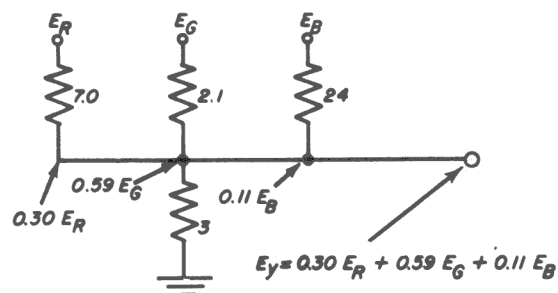


Fig. 40-9

signal carries information about the green-magenta content of the scene.

The I and Q signals together are called the *chrominance* signals. Together, the luminance and chrominance electrical signals completely describe a color, just as the brightness, hue and saturation sensations completely describe the color.

As a result of the filters in the I - and Q -channels shown in the block diagram of Fig. 40-8, the video response of the I channel ranges from 0 to 1.5 mc; and the video response of the Q -channel runs from zero to 0.5 mc. These responses are shown in Fig. 40-10, along with the response of the E_Y signal. The video range of this signal is from 0 to 4.0 mc, just as in the black-and-white case. Examination of this figure shows that in the range from 0 to 0.5 mc, all three signals (E_Y , E_I , E_Q) are present. Thus the three quantities needed to completely and correctly describe a color are present in this range, just as the eye requires. The three signals combine to correctly reproduce colors in large areas. In the video range from 0.5 mc to 1.5 mc, only the E_Y and E_I signals are present. These two signals combine to reproduce colors in this range as mixtures of orange and cyan, just as the eye requires. In the range above 1.5 mc, no color signals are present, but, in this range, no color is required by the eye.

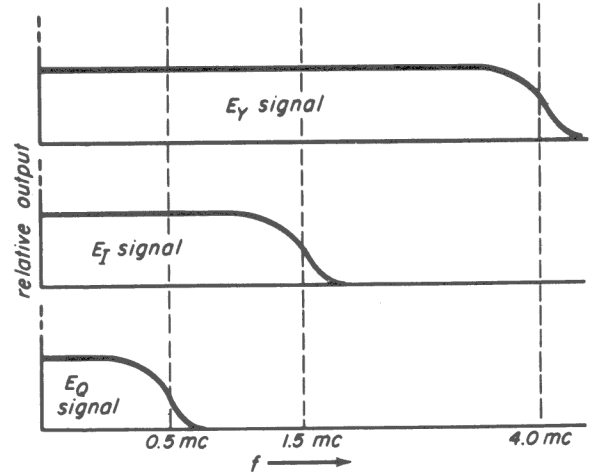


Fig. 40-10

information is already occupied by the E_Y signal. If color is to be transmitted without requiring additional spectrum space, then two color signals must be transmitted in the same spectrum space as that apparently already occupied. How can this be done? First, extensive mathematical and experimental analysis shows that the monochrome signal really does not fully occupy the region from 0 to 4 mc. Instead, the signals produced by scanning a television picture are always concentrated around certain frequencies, in a very regular pattern as shown in Fig. 40-11. In between each of these filled regions, there are gaps where signals do not appear regardless of the nature of the picture being transmitted. It is in these gaps in the spectrum of the monochrome signal that the color information is transmitted. The energy in a monochrome signal is concentrated at harmonics of the horizontal scanning frequency. In between these intervals, at odd harmonics of half the line scanning frequency, are the

40-6. TRANSMITTING THE COLOR SIGNALS

It appears from Fig. 40-10 that the entire 4 mc of spectrum space allotted to picture

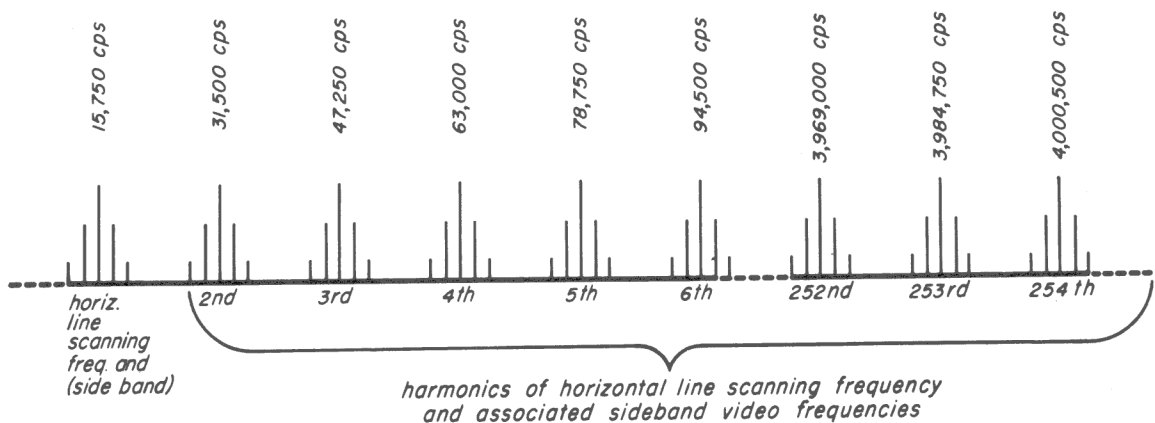


Fig. 40-11

gaps where no monochrome signal energy is present. The color information is fitted into each of these gaps. In this way both signals are transmitted together in the same spectrum space, with neither interfering with the other.

In order to fit the separate I - and Q -signals into these gaps, they are first combined into a single chrominance signal, by a special modulating technique to be described shortly. They are combined so that both pieces of information (I and Q) are carried by this single signal but in such a way that I - and Q -signals can be separated again by the receiver. This combined signal is obtained as a modulated signal at the *color subcarrier* frequency of 3.579545 mc. This exact carrier frequency is chosen because it is an exact multiple of an odd harmonic of one-half the line scanning frequency. All sidebands produced by the modulation process are therefore also odd harmonics of one-half the line scanning frequency. Thus all the sideband signals fall exactly into the gaps in the monochrome signal as shown in Fig. 40-12.

The I - and Q -signals are combined into a single chrominance signal by a process known as two-phase modulation. Two balanced modulators are used. A signal at the color subcarrier frequency (called 3.58 mc for convenience) is applied to each of the balanced modulators, but these two signals are separated in phase by 90 degrees.

The output of the I modulator is proportional to the I -color video input signal, and the output of the Q modulator is proportional to the Q -color video input signal.

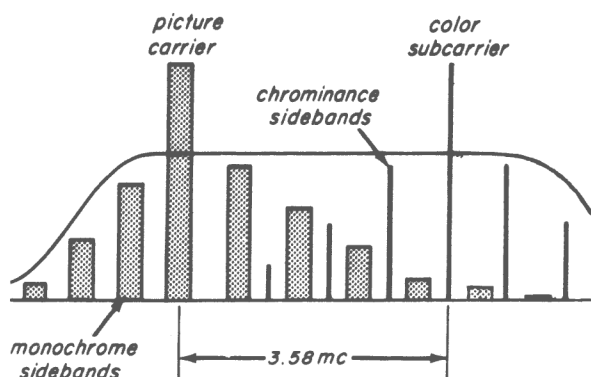


Fig. 40-12

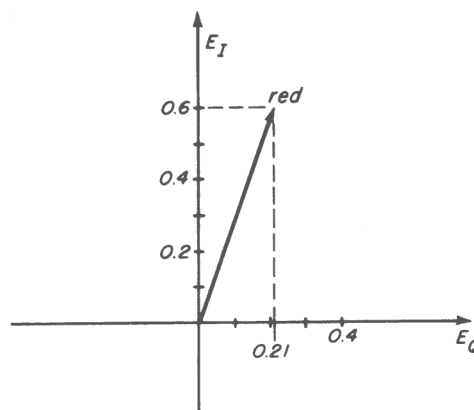


Fig. 40-13

The outputs of the two modulators are connected together so that they add, but because of the 90-degree phase relationship of the output signal their sum is a *vector sum* that varies in phase and amplitude according to the I - and Q -color signal input. For example, when a fully saturated red is being transmitted, the output of the red camera is 1.00 volts and the output of the blue and green cameras is zero. Using the formulas for E_I and E_Q , it is determined that the E_I voltage is 0.60 volts, and the E_Q voltage is 0.21 volts.

The output of the I modulator will then be proportional to 0.60 volts, and the output of the Q modulator will be proportional to 0.21 volts. The vector sum of these two outputs is shown in Fig. 40-13. Now, when blue is transmitted, the red and green camera outputs are zero, and the blue camera output is 1.00 volts. Using the same formulas, it is determined that the E_I signal is now -0.32 volts, and the E_Q signal is now $+0.31$ volts. The effect of a negative input voltage to the modulator is to reverse the polarity of its input. Thus the output of I modulator is proportional to 0.32 volts, and its output is opposite in polarity, as shown in Fig. 40-14. The output of the Q modulator is proportional to 0.31 volts. The vector sum is shown in the figure, which shows that the vector sum of the chrominance signal for blue is at a different phase angle than that for red. In the same manner the vector sum for all the major colors can be worked out, and are as shown in Fig. 40-15. It is characteristic of the two-phase modulation process that every color produces its own unique phase angle. When the color is less saturated, the I and Q voltages

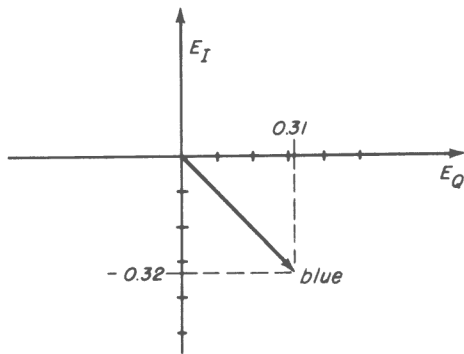


Fig. 40-14

are reduced, but in the same proportion. The length of the vector is reduced, but its phase angle remains the same. The colors are identified by measuring the phase angle with respect to a reference phase, whose location is shown in the figure. For reasons beyond the scope of this lesson, the reference phase is located 57-degrees from the I phase. For purposes of making this phase measurement at the receiver, about 8 cycles of the 3.58-mc carrier signal, at the reference phase, are transmitted as a part of the composite color signal. These eight cycles, which are termed the *color burst*, are transmitted once every horizontal line on the back porch of the horizontal sync pulse, as shown in Fig. 40-16. Because the burst occurs during horizontal blanking, it is not seen on either color or black-and-white receivers.

All of the essential features of the color television transmitting process have now

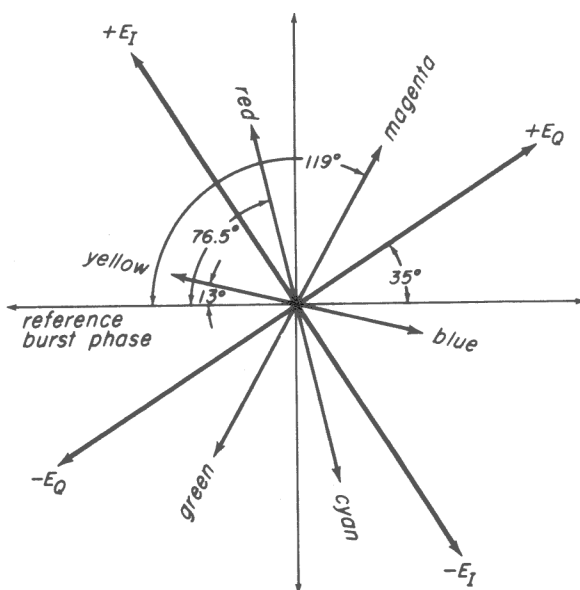


Fig. 40-15

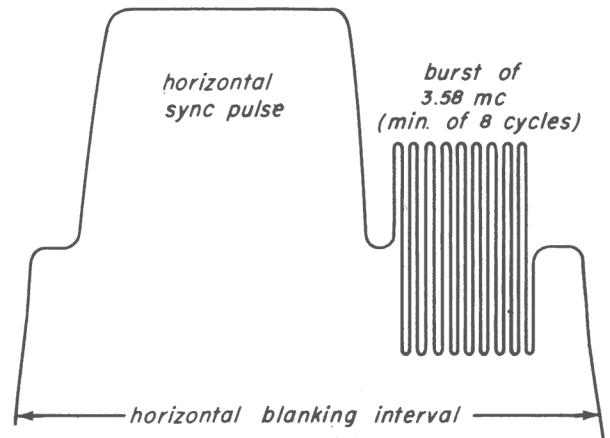


Fig. 40-16

been introduced. Let us now review the operation of the entire system, which is shown in simplified form in Fig. 40-17. Each tiny element of the scene is viewed at the same instant by each of the three camera tubes. By means of the three colored filters in front of the camera tubes, one responds only to red light, another to green light, and the third to blue light. The output of the three cameras consists of three signal voltages, E_R , E_G , and E_B which are proportional to the amount of red, blue, and green in each element of the scene. These three

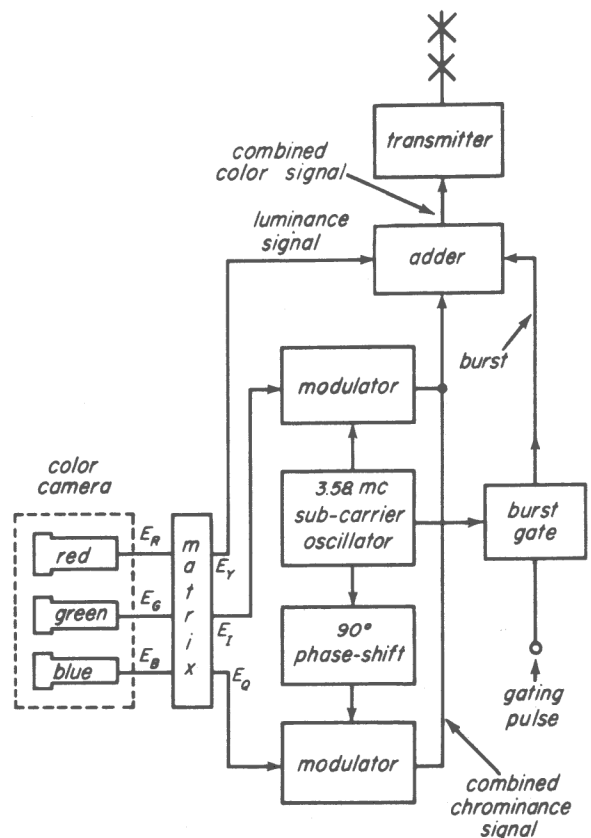


Fig. 40-17

signal voltages are applied to the matrix, which takes certain portions of the three voltages to make three new signals, E_Y , E_I and E_Q . The E_Y is a signal that very closely resembles the output of a monochrome camera for the same scene. It forms the fine detail in the picture, and is used by monochrome receivers to make pictures from a color broadcast. The E_I signal carries information as to the orange and cyan content of each element of the scene, and the E_Q signal carries information as to the green and magenta content of each element of the scene. The two chrominance signals are combined into one by applying them to two balanced modulators, whose output is combined. The output signals of the modulators are 90 degrees out of phase with each other so that the combined output varies in phase and amplitude according to the color being transmitted. The hue is identified by the phase angle of the chrominance signal with respect to burst, and the saturation is identified by the amplitude of the chrominance signal.

40-7. TRICOLOR KINESCOPIES

At the receiver the color television signal is analyzed to obtain three video signals that give the amount of red, green, and blue in each element of the original scene. These three video signals are proportional to the E_R , E_G , and E_B camera signal output voltages. A full-color reproduction is produced by using these color video signals to produce three colored images of the scene — one in red, one in green, and one in blue. The color picture is recreated by combining these three separate images in such a way that the eye sees the mixture of the three images. One way in which this can be done has already been shown in Fig. 40-5, using three separate images whose images are superimposed by optical methods.

Another method, which is the one most used, is to produce the three separate images on the single screen of a *tricolor* kinescope, so close together that the eye cannot see the separate red, green, and blue images. The three images are so close together that the eye combines them, and sees the mixture of the three colored images, which is a full-color picture.

The construction of the shadow-mask type of tricolor kinescope is shown in Fig. 40-18. The screen is covered with a regular pattern of small dots of fluorescent phosphor, as shown in Fig. 40-19. The phosphor is of three kinds so that the dots glow red, green, and blue when excited by an electron beam. The dots are touching, and are so small that they cannot be seen individually at any normal viewing distance. Some idea of the small size of the dots can be obtained by noting that there are about 7,000 dots to the square inch, and a total of over 1 million phosphor dots for a 21-inch screen.

Inside the neck of the kinescope are three identical electron guns. The electron beam from one of these guns is caused to strike only red phosphor dots, and this gun is referred to as the red gun. The second gun strikes only green dots and is referred to as the green gun. Similarly, the third blue gun strikes only blue dots. Of course, the electron beams from the three guns are identical; it is only when the electron beams strike different phosphor dots that different colored light is given off. The tricolor kinescope may be thought of as the three separate red, green, and blue kinescopes of Fig. 40-5 all merged into one glass envelope. Thus, when the red video signal E_R is recovered in the receiver, and applied to the red gun, a picture in red of the red parts of the original scene is traced out on the kinescope. Similarly, the green video signal applied to the green gun produces a green image, and the blue video signal applied to the blue gun traces out a blue image. These three images are automatically superimposed due to the structure of the phosphor screen. The eye combines the images and sees a full-color reproduction of the original scene.

In order for the tricolor kinescope to operate properly, it is necessary to insure that only the red beam strikes red dots, and likewise that the green beam strikes only green dots, and the blue beam strikes only blue dots. This is done by an ingenious arrangement whose operating principle is shown in Fig. 40-20. The three electron guns are arranged inside the neck so that they are 120 degrees apart, as if they were at the corners of an equilateral triangle.

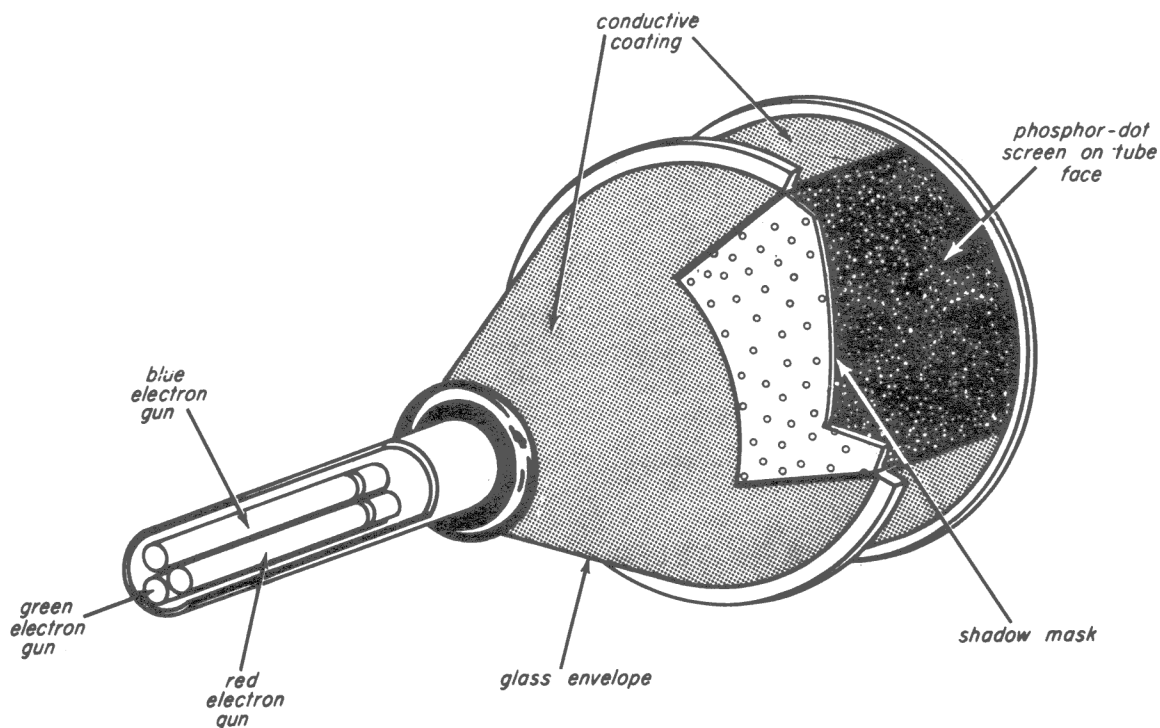


Fig. 40-18

The phosphor dots on the screen are arranged in three-dot clusters or trios in a pattern that is related to the three electron guns as shown in the figure. A perforated mask, called a shadow mask, is placed between the guns and the phosphor screen. There is one hole in the shadow mask centered over every trio of dots on the screen, as shown by the dashed lines in Fig. 40-19.

The angle of approach of each beam is adjusted so that they go through the hole in the shadow mask at the proper angle to strike their correct colored phosphor dot, as shown in Fig. 40-20. As the three guns scan the picture area from left to right and top to bottom, the shadow mask keeps each beam from striking wrong phosphor dots. For example, as the red beam scans horizontally from points *a* to *b* in the figure, it must pass over green and blue dots. However, the shadow mask prevents the beam from reaching the screen and exciting the wrong dots. Only when it has reached the position *b* where there is another red dot is the red beam again allowed to reach the screen through another hole.

For proper color reproduction, it is necessary for the three beams to cross over or *converge* at the shadow mask, so that all three beams go through the same hole in the shadow mask as each part of the screen is scanned. This is accomplished by applying special control signals, called convergence

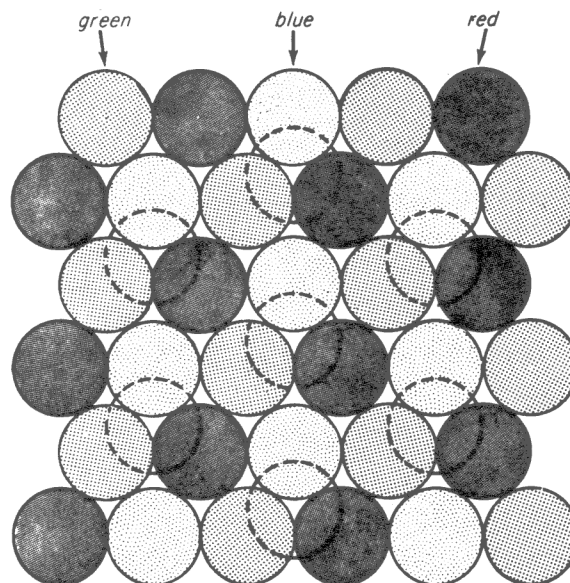


Fig. 40-19

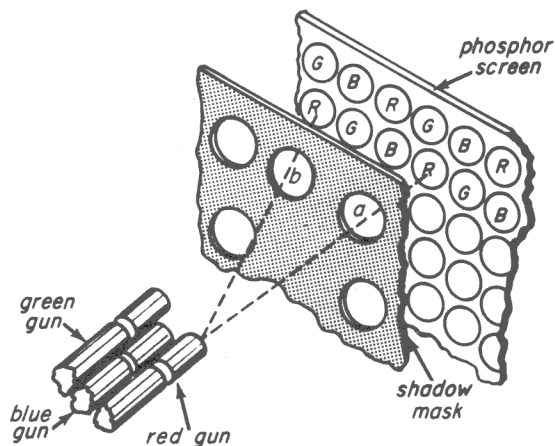


Fig. 40-20

signals, to each of the three kinescope beams.

40-8. PRINCIPLES OF COLOR TELEVISION RECEIVERS

The color television receiver recreates from the transmitted composite color signal the three camera signals, E_R , E_G , and E_B . These signals are applied to the tricolor kinescope to produce a full-color picture. The major sections of a color television receiver are shown in block diagram form in Fig. 40-21. The diagram shows a number of color sections added on to a black-and-white receiver. However, this is done only for purposes of explanation. It should not be thought that in actuality a color receiver is a monochrome receiver with a few added sections for color. For best performance, color receivers are completely designed

from the kinescope to the antenna terminals, with color reception in mind.

In the receiver the composite color signal is amplified and detected, in the same manner as in monochrome receivers. Thus, the output of the black-and-white portion of the receiver is a composite color *video* signal. This signal, you will recall, consists of the luminance signal, sync and blanking pulses, the chrominance signal, and the color burst which rides on the back porch of the horizontal sync pulse. These various parts of the color signal are separated at this point in the color receiver, and each sent to the proper receiver section. The luminance signal is applied directly (after additional video amplification) to the receiver matrix, where it will be added to other signals to produce the E_R , E_G , and E_B voltages.

The combined chrominance signal is separated from the composite video by the bandpass amplifier, whose response is shown in Fig. 40-22. The bandpass amplifier will only admit signals from about 2.5 mc to 4.1 mc. The chrominance signal is within this range. The combined chrominance signal is a 3.58-mc signal that varies in phase and amplitude according to the color being transmitted. It is now necessary to separate this combined signal into its I and Q components. This is done by the color demodulators, whose action is exactly the opposite of color modulators at the transmitter. In the modulation process the separate I - and Q -video signals are

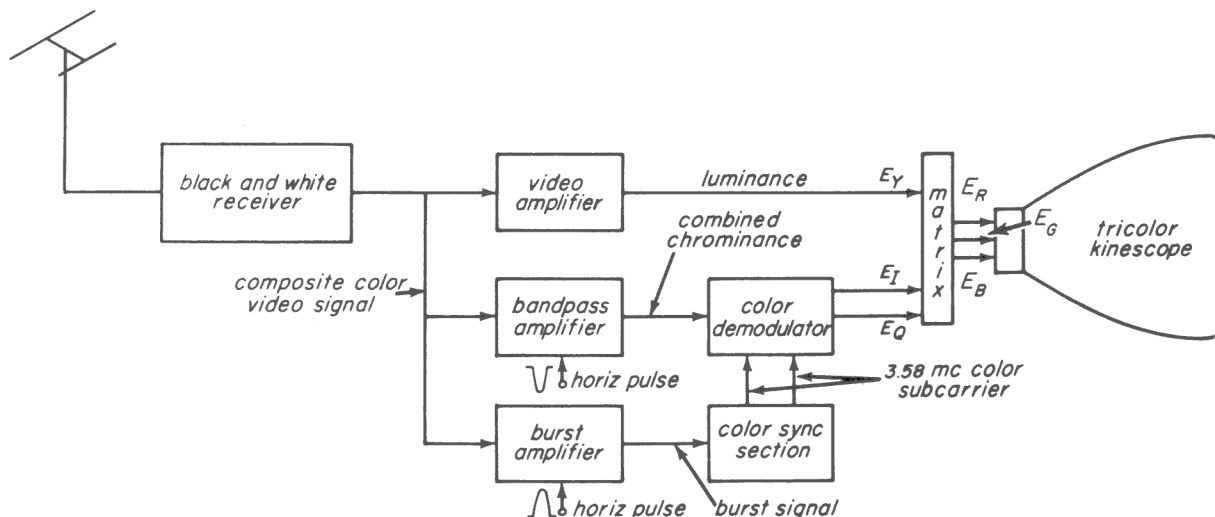


Fig. 40-21

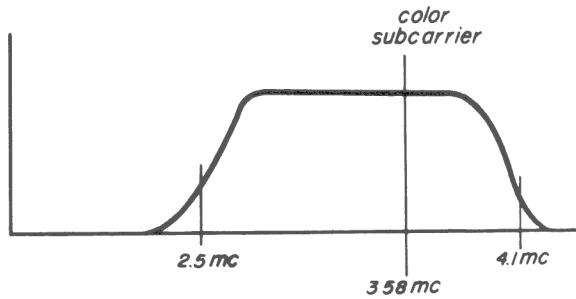


Fig. 40-22

combined into a single 3.58-mc chrominance signal. In order to do this the two receiver modulators must be supplied with two 90 degrees out-of-phase 3.58-mc signals. These signals are produced by a 3.58-mc oscillator whose phase is accurately controlled by the color burst acting through the color sync section.

The burst is separated from the composite video signal by the burst amplifier. This amplifier is held cut off except during burst time when a high voltage pulse from the high-voltage transformer turns the burst amplifier on and allows the burst to pass through. Also the burst is kept out of the color demodulators by a similar pulse from the high voltage transformer, which turns the bandpass amplifier off during burst time.

The phase of the incoming chrominance signal in each demodulator is compared with the phase of the 3.58-mc signal from the color sync section. In this way the separate *I*- and *Q*-video signals are obtained.

The *I*- and *Q*-signals are applied to the receiver matrix, where they add with the luminance signals to produce the red, green, and blue video signals. Here again, the action of the receiver matrix is just the inverse of the transmitter matrix. At the transmitter, the input to the matrix is E_R , E_G , and E_B and the output is E_Y , E_I , and E_Q . At the receiver, the input to the matrix is E_Y , E_I , and E_Q , and the output is E_R , E_G , and E_B . These signals are applied to the red, green, and the blue guns of the tri-color kinescope, and a full color picture is produced.

When black-and-white programs are transmitted, only the E_Y signal is present. The color sections of the receiver are inoperative. The luminance signal is applied equally through the matrix to all three guns, thus producing a black-and-white picture.